

## C. Cermet Composites for Wear Applications

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### Objectives

- Optimize material processing of a cermet material comprised of hard titanium carbide (TiC) particles in a tough nickel aluminide (Ni<sub>3</sub>Al) metallic matrix for fabrication of near-net-shape components with low wear and scuffing properties.
- Optimize material processing parameters for a tungsten carbide (WC) powder/cast iron composite material with low wear and scuffing properties.
- Develop potential applications in heavy-duty diesel engine systems for these two previously identified unique wear-resistant materials.

### Approach

- A single composition of TiC/Ni<sub>3</sub>Al material is to be processed under optimized powder blending, molding and sintering parameters to produce test pieces and prototype near net shape injection molded components for evaluation of properties.
- Sample pre-forms with varying densities and porosity distributions of WC powder are to be infiltrated by cast iron, followed by sample characterization.

### Accomplishments

- Completed initial TiC/Ni<sub>3</sub>Al injection molding equipment modifications, material binder formulation, mixing/preparation, injection molding trials, debinder and binder decomposition tests, sintering development, and test bar property evaluation.
- Evaluation and comparison of WC compacts showed a change in porosity distribution from the original work that produced fully dense test pieces.

### Future Direction

- Further optimization of binder decomposition and sintering cycles for the TiC/Ni<sub>3</sub>Al are planned to achieve the 99+% density needed. This will also establish the design shrinkage factor and allow the prototype tooling to be built.

- A small  $2 \times 2$  full factorial test matrix is planned to investigate the distribution of porosity in the WC pre-forms to validate the porosity distribution theory and demonstrate success in wear prediction of the WC/cast iron composite surface.

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## **Introduction**

The continuing reduction of allowable engine combustion emissions in current and future standards requires operation at higher injection pressure and reduced component clearances in fuel system components. New materials that exhibit very hard wear-resistant surfaces are needed by industry to use as injector plungers and contact wear surfaces for diesel engines.

Work done under the previous DOE Cooperative Agreement DE-FC05-97OR22538 found two cermet materials that Cummin's was interested in pursuing for possible production implementation in diesel engines.

The first material (TiC/Ni<sub>3</sub>Al) is a TiC powder in an Ni<sub>3</sub>Al metal matrix developed in collaboration with Oak Ridge National Laboratory (ORNL) and CoorsTek. Extensive testing and analysis was done by all three partners to help optimize the processing and properties. The composition with the suite of properties most closely matching Cummins' needs for fuel injector materials was chosen for further optimization of the powder and processing.

The second material (WC/cast iron) is a WC compact to be added to casting molds prior to pouring that would allow cast iron infiltration into and through the compact to produce a localized hard wear-resistant surface. Initial infiltration of the compacts showed good wetting and complete infiltration. The wear properties of these surfaces were between the wear properties of zirconia and D4 tool steel (conventional fuel injector materials). Repeat infiltrations with compacts from additional pressings resulted in no iron infiltration of the compact. The lack of repeatability led to the current work of characterizing and documenting the

compact manufacture and then optimization of the iron infiltration.

## **Approach**

This program covers investigation and material processing optimization for two unique wear-resistant materials for potential application to diesel engine system components. The first material is a cermet comprised of TiC particles in an Ni<sub>3</sub>Al matrix. A single composition of this material was chosen for the material processing development to obtain both the optimized raw material processing and the optimized consolidation and sintering parameters to produce a final component with the required low wear and scuff properties for a diesel engine system application. The material processing optimization is in process at CoorsTek with guidance from ORNL. Property evaluations will be conducted at CoorsTek, ORNL, and Cummins to characterize the density, strength, fracture toughness and wear of the material.

The second material is a cermet comprising WC particles in a cast iron matrix. The optimization of WC compact components and processing will be studied, along with the effects of cast iron composition and heat treatment. Evaluation of the wear and scuffing properties for the different cermet iterations will be used to guide the optimization effort. Compact manufacture is in process at Applied Powder Products, and the iron casting is scheduled at Case Western Reserve University (CWRU).

## **Results**

The process optimization of TiC/Ni<sub>3</sub>Al composition has been finalized for the equipment (double planetary mixer with vacuum/Ar atmosphere operation), binder, mixing parameters, and initial molding

parameters. The binder formulation was chosen to provide wetting of the powder during mixing, a strong feedstock matrix for injection molding, and a broad working viscosity at high solids loading. The molding trials conducted over several batches were used to optimize part weight, with the last batch demonstrating a narrow distribution in weight ( $5.447 \pm 0.0104$  g). Debinding and sintering trials have produced test bars for evaluation. The debinding and sintering development is continuing.

The initial trial batch of material sintered to 98% density and had a flexural strength of 787 MPa (below the target value of 1032 MPa). The strength values and statistical distribution of the values are given in Figure 1. The wide spread in values and lower-than-anticipated strength are thought to be due to the lower density with a larger than expected flaw population. Additional flexural strength tests (three-point bending) were conducted on the broken bars from the original strength testing; the results are shown in Figure 2. The three-point bending showed strength 70% greater than the four-point bending. This increase in strength was greater than would be expected from just differences in test span and volume of material. The distribution of critical flaws

**IM Cermet #003 (CoorsTek)**

Mean Strength	787 MPa
Std Dev.	153 MPa
Coeff of Variation	20 %
No. Specimens	10
Max Strength	979 MPa
Min Strength	449 MPa

**Figure 1.** Flexural strength of TiC/Ni<sub>3</sub>Al cermet in four point bending (CoorsTek).

**IM Cermet #003 (CoorsTek)**

Mean Strength	1345 MPa
Std Dev.	131 MPa
Coeff of Variation	10 %
No. Specimens	6
Max Strength	1545 MPa
Min Strength	1215 MPa

**Figure 2.** Flexural strength of TiC/Ni<sub>3</sub>Al cermet in three point bending (CoorsTek).

and work hardening of the intermetallic Ni<sub>3</sub>Al phase are additional factors that could influence the failure mechanism in this composite microstructure.

WC compacts were pressed and sintered by Applied Powder Products using 1- $\mu$ m powder. These compacts were placed in sand molds at CWRU and infiltrated with molten iron. Upon cooling, the compacts were found to have no iron infiltration (Figure 3). This result showed that additional work was needed to optimize the compact manufacturing and bring the process back



**Figure 3.** Tungsten carbide compact showing no iron infiltration after casting.

to the successful infiltration in previous castings. Evaluation of these WC compacts and comparison of the porosity distribution with that of WC compacts from 2001 showed a significant difference in density distribution at larger pore sizes (Figure 4). This difference in pore distribution is thought to impact the penetration of the cast iron into the compact during casting.

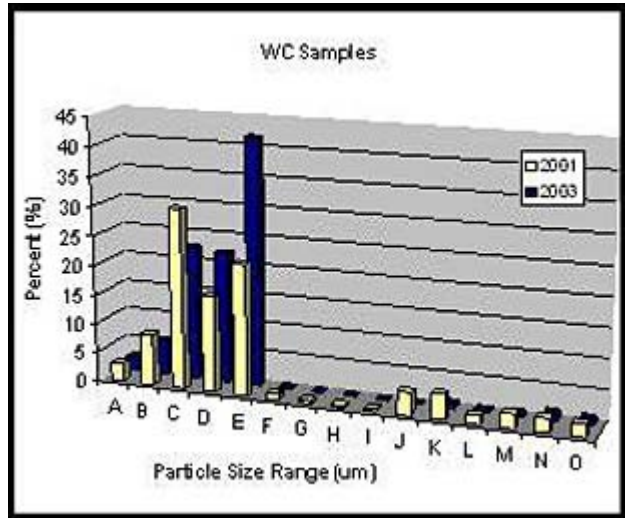


Figure 4. Particle size distribution comparison for WC compacts from mercury porosimetry measurements.

## Conclusions

Process optimization work for the TiC/Ni<sub>3</sub>Al powder is on schedule, and the delivery of test pieces for wear evaluation and correlation to the previous material studies is anticipated by the end of 2003. The density is slightly below the necessary level of 99+%, affecting the strength measurement and giving a wide spread in flexure strength.

The porosity distribution for the WC powder compacts in this work was found to be different from that in previous work. The current samples did not allow penetration of cast iron into the WC powder compact.